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# LATE ORDOVICIAN DEEP-WATER BRACHIOPOD FAUNA FROM RAHEEN, WATERFORD HARBOUR, IRELAND

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## Abstract

The Raheen Formation at Newtown Head in Waterford Harbour is a small isolated section of Ordovician rocks, dominated by volcanics of the Duncannon Group, but with interbedded fossiliferous shales. Although a brachiopod and trilobite dominated fauna has been known since the mid-19<sup>th</sup> century only the trilobites and cystoids have been assessed in modern terms. This paper describes the brachiopod fauna for the first time. The assemblage from Raheen is overwhelmingly dominated by the dalmanelloid *Onniella*, with the small plectambonitoid *Sericoidea* comprising the second most numerous species; both are represented by new species. This revision has also identified a wide range of other genera, but all in very small numbers. These include an obolid, a paterulid, *Paracraniops* and *Orthisocrania divaricata* (M'Coy) amongst the non articulated brachiopods. Articulated genera present include the orthoids *Nicolella*, *Ptychopleurella*, *Sulevorthis*, *Skenidioides* and the plectambonitoid *Leptestiina*. Very rare forms include *Idiospira?* and *Palaeostrophomena* together with possibly *Biscuspina* and *Sowerbyella*. The brachiopod revision supports the late Caradoc (early Katian) age indicated by the trilobite fauna. The trilobite fauna generally indicates a probable deeper-water environment and the brachiopod assemblage confirms an outer shelf environment. Although elements of the assemblage indicate affinity with the well-defined Late Ordovician *Foliomena* fauna, it probably occupied a more shoreward position.

## **Introduction**

During the late Ordovician deeper-water brachiopod biofacies were commonly dominated by small pedunculate dalmanelloids and recumbent plectambonitoids. The Raheen locality, just north of Newtown Head, in Waterford Harbour, County Waterford (Fig. 1) has yielded one such brachiopod association which this paper describes. The fauna is of late Caradoc age, in terms of the UK regional series, equating with the lower part of the global Katian Stage. The trilobite assemblage from this locality has been previously described (Owen *et al.* 1986) and this paper complements that work in providing analysis and description of the brachiopods which comprise an equally important component of the whole fauna. Older (late Darriwilian-early Sandbian) more diverse brachiopod faunas from the regionally-adjacent Tramore and Dunabrattin formations (Carlisle 1979) have recently been monographed (Liljeroth *et al.* 2017), and reflect shallow sub-tidal to outer-shelf palaeoenvironments.

## **Stratigraphy and Faunas**

The Raheen Formation shales were probably first sampled in the 1840's as both Portlock (1843) and M'Coy (1846) illustrate material from the locality. Du Noyer and Baily (1865) listed the fauna from Raheen, as locality 3 in the table of fossil localities in the Geological Survey of Ireland (GSI) Memoir for the area. In addition, Baily (1869) mentioned sparse graptolites occurring at Raheen in conjunction with 'numerous Caradoc-Bala fossils.' These GSI specimens were examined by Reed (1899) but had become largely unavailable to Owen *et al.* (1986) in their documentation of the trilobite fauna. Subsequently the GSI collection was curated and catalogued (Parkes and Sleeman 1987) and was available to us to supplement the extensive collections made by R. P. Tripp and S. F. Morris in the early 1980s (Owen *et al.* 1986) which form the core material described.

Cowper Reed (1899) first described the Raheen shales as a fossiliferous unit within the varied Ordovician succession north of Newtown Head, County Waterford. Reed (1899) discussed the entire succession in detail and presented comprehensive faunal lists, including six brachiopod species from Raheen, based on his own and previous collections. The Ordovician rocks since have been formally named in a series of publications (Mitchell *et al.* 1972; Williams *in* Williams *et al.* 1972; Brenchley *et al.* 1977; Carlisle 1979; Harper and Parkes *in* Fortey *et al.* 2000) in which the Raheen Formation was located within the volcanics, volcanoclastics and clastic sediments of the Duncannon Group.

In the Geological Survey of Ireland's more recent map compilation (Tietzsch-Tyler and Sleeman 1994) the Raheen shales were considered as one of several members of the Campile Formation, constituting the main unit of dominantly volcanic rocks within the Caradoc Duncannon Group through Waterford and Wexford. They were correlated with the Newtown Head Member of the sequence seen at Duncannon itself, where Gardiner (1974) first named the Duncannon Group. In the more recent Ordovician Correlation Chart, Harper and Parkes (*in* Fortey *et al.* 2000) viewed the Raheen Formation as the youngest unit in the Tramore district, based on the trilobite data of Owen *et al.* (1986). It is clear that the Raheen Formation is a poorly constrained unit open to varying interpretations within the regional geological framework. This revision of the brachiopod fauna therefore provides valuable additional data in clarifying the environment of deposition and the correlation of the Raheen Formation.

The formation is locally fossiliferous, dominated by trilobites and brachiopods together with much less common bryozoans, gastropods, machaeridians, possible ostracods and graptolites (Owen *et al.* 1986). Elements of the fauna were described in the 19th century by Portlock (1843), M'Coy (1846), Salter (1849, 1864) and Davidson (1866). These data were enhanced by Reed's faunal lists (1899) for the group. More recently Paul (1984; 1997) has described part of the echinoderm fauna in his



monograph on British Ordovician cystoids. Our collections include additional material of two forms of cheirocrinid cystoids.

In a detailed reassessment of the section, Owen *et al.* (1986) described and illustrated the Raheen trilobite fauna, refining age and palaeoenvironmental interpretations for the enclosing sandy and ashy mudstones. The trilobite fauna, consisting of 14 taxa dominated by *Tretaspis ceryx* Lamont and *Ampyx austinii* Portlock, indicates correlation with the upper Caradoc and deposition in a fairly deep-water setting.

This paper is based upon several collections. The brachiopod material collected by Ron Tripp and Sam Morris in 1981 and 1982 (see Owen *et al.* 1986) was passed to Harper. Additional collections were made by Harper (and Ian Mitchell) as well some further collecting by Owen. Owen *et al.* (1986) did not have access to much of the Geological Survey of Ireland (GSI) 19<sup>th</sup> century fossil collection at that time, but these have now become fully curated and accessible (Parkes and Sleeman 1997), and are included in this examination of the Raheen brachiopod fauna.

Owen *et al.* (1986) provided a stratigraphical description documenting the sampled horizons. This paper utilises the same sample numbers and horizons, although not all specimens are as precisely defined. It is clear, however, that virtually all collections, both historical GSI collections and more modern ones have been made from a comparatively restricted succession of shales, only 36.5 m thick, to the south of the Raheen stream. A secondary locality to the north of the stream has also provided a second collection with nearly identical characteristics. Two additional samples are included in this analysis, one below the previous base and one close to the top of the fossiliferous strata. In the light of new collections by Parkes (1994) and newly accessible GSI collections, Owen and Parkes (2000) revised the Burrellian (late Sandbian in terms of the international Ordovician stages) trilobite faunas from localities in Wexford and Waterford, which shared many taxa with Raheen. In view of this

Owen and Parkes (2000) reappraised the age of the Raheen fauna but concluded that a late Caradoc (early Katian) age was still the best assessment. The new brachiopod data here are also consistent with that, as there are few well-characterised taxa of good biostratigraphical utility to refine that age assignment. The closest locality in terms of the fauna is also called Raheen, but is situated near Enniscorthy in County Wexford. An abundant but unidentified dalmanelloid there (*in* Parkes 1994) is probably *Onniella*, and the other main elements of the fauna are *Chonetoidea* or *Sericoidea* and the trilobites *Tretaspis* and *Ampyx* (see Owen and Parkes 2000). These were also found in the ashy mudstones.

### **Brachiopod Association**

The onshore-offshore expansion of the Ordovician marine fauna into deeper-water environments is well established (Jablonski et al. 1983; Sepkoski and Sheehan 1983; Sheehan 2001) creating an important dimension to the Great Ordovician Biodiversification Event (Harper 2006). This offshore migration of taxa has been established in detail at both regional (Bassett *et al.* 2002) and local levels (Mergl 1999; Hansen and Harper 2008) amongst brachiopod faunas and similar patterns are seen in other benthic groups. This expansion probably exploited vacant ecospace or habitats occupied by relict elements of the Cambrian fauna, creating a range of new communities culminating, during the Late Ordovician, with the well-documented deep-water brachiopod *Foliomena* fauna (Harper *et al.* 1999; Rong *et al.* 1994, 1999; Zhan and Jin 2005) occupying Benthic Assemblage Zone 5 and beyond and associated with the long established atheloptic – cyclopygid trilobite faunas (Fortey and Owens 1987; Owen and Bruton 2012). These late Ordovician faunas had a nearly global distribution around the margins of the larger continents. The velocity of such onshore – offshore expansion was probably rapid, with the transitions, in deeper-water environments, from the Cambrian fauna to the Palaeozoic fauna commencing in the Floian (Early Ordovician) and finishing in the Katian (Late Ordovician). There were apparently regional variations, the process occurring faster around Gondwana and slower around Laurentia (Bassett *et al.* 2002). Such deep-water brachiopod faunas attained a relative stability

and longevity, with, for example, the *Dicoelosia*-type community ranging from the Late Ordovician to the Early Devonian (Watkins *et al.* 2000). The *Foliomena* brachiopod fauna was predominant in deep-water facies during the Late Ordovician but relatively little is known about its relationship to other deep-water assemblages such as the *Onniella-Sericoidea* association described here.

The *Foliomena* fauna (Harper 1979, 1980) is dominated by small, thin-shelled brachiopods, usually of moderate diversity and reported from some 30 localities globally, ranging in age from late Darriwilian to Katian (Rong *et al.* 1999; Zhan and Jin 2005; Liang *et al.* 2014). Assemblages dominated by *Onniella* and *Sericoidea* (or *Chonetoidea*) are less well known. Jaanusson (1984) placed these and related assemblages in a crude environmental context. He considered that outer shelf and upper slope associations were characterised by the plectambonitoids *Chonetoidea* and *Sericoidea* together with lingulates. These assemblages have been compared with the *Foliomena*-type faunas and may have developed adjacent to them or upslope. In coarser more proximal sediments these small plectambonitoids were joined by the dalmanelloid *Onniella* which is less common and smaller in darker sediments where the nonarticulate brachiopod *Hisingerella* may be more abundant (Harper *et al.* 1985; Hansen and Harper 2008). Associations dominated by *Onniella* and *Chonetoidea* or *Sericoidea* are thus more typical of the outer shelf and variants have been recorded from the upper Caradoc and lower Ashgill interval from the margins of Laurentia (Bretsky 1969; Harper 1979, 2001; Candela 2001, 2003), Avalonia (Wright *in* Ingham 1966; Lockley 1980) and Baltica (Harper *et al.* 1985; Hansen and Harper 2008).

The Raheen fauna is dominated by small *Onniella* together with *Sericoidea* suggesting a more proximal position than the *Foliomena* fauna on the outer shelf associated with coarser sediment. Elsewhere in the Leinster area faunas dominated by *Chonetoidea* have been reported from older rocks (Lower Caradoc) at Greenville (Parkes 1994; Parkes and Harper 1996) suggesting the persistence of this outer shelf assemblage on this part of the Leinster terrane. The Raheen fauna is compared with other closely coeval assemblages from elsewhere using non-metric multidimensional scaling (NMDS), analysed by the Raup-Crick coefficient. The database is that assembled in Harper *et al.* (2013) where

the results of that analysis were illustrated (figs 11.10, 11.11). The additional data from Raheen have been added and analysed; Raheen plots close to a number of the Laurentian, Laurentian marginal, Asian and Anglo-Welsh localities (Fig. 2). The Raheen fauna is located in deep water, many of its elements are widespread and in a regional context it indicates a commonality of faunas as the Avalonia, Ganderian and Laurentian plates converged in the Late Ordovician and early Silurian. Nevertheless the fauna developed during a transgressive interval, marking an offshore colonisation of deeper-water environments, when elsewhere, in many parts of the World, similar facies were inhabited by the *Foliomena* fauna (Rong et al. 1999). Table 1 summarises the brachiopod data for all sampled levels and collections at Raheen.

### **Systematic Palaeontology**

Brachiopod material is housed in the Natural History Museum, Dublin, Ireland (Prefixed NMING : F). Also included in this collection is most of the trilobite fauna that was not figured in Owen *et al.* (1986) and the other faunal elements in their samples. The figured and some representative trilobite material described by Owen *et al.* (1986) is in the Natural History Museum, London. Owen *et al.* informally numbered material with the prefixes a, b, c and d. and some without a prefix. The Geological Survey of Ireland also holds a large collection from Raheen that includes material figured here (Prefixed GSI: F).

Subphylum LINGULIFORMEA Williams *et al.* 1996

Class LINGULATA Gorianski & Popov, 1985

Order LINGULIDA Waagen, 1885

Superfamily LINGULOIDEA Menke, 1828

Family OBOLIDAE King, 1846

obolid indet.

Fig. 3a

1899 *Lingula brevis* Portl.; Reed, p. 723.

*Remarks.* The small sample of obolid brachiopods is neither adequately well preserved nor complete enough to allow description.

Family PATERULIDAE Cooper, 1956

paterulid indet.

Figs. 3f, g

?1899 *Orbiculoidea oblongata* Portl.; Reed, p. 723.

*Remarks.* Several of the horizons from collections that have been made at Raheen include small numbers of poorly preserved paterulid brachiopods which are not satisfactory for description or well enough preserved to allow more accurate identification.

Subphylum CRANIIFORMEA Popov *et al.*, 1993

Class CRANIATA Williams *et al.*, 1996

Order CRANIOPSIDA Goriansky & Popov, 1985

Superfamily CRANIOPSOIDEA Williams, 1963

Genus *PARACRANIOPS* Williams, 1963

*Paracraniops* sp.

Figs. 3b-e

1899 *Pholidops? balcletchiensis* Portl.; Reed, p. 723.

*Remarks.* Small numbers of poorly preserved *Paracraniops* occur in several horizons at Raheen but the material is not satisfactory for description or well enough preserved to allow more precise identification.

Order CRANIIDA Waagen, 1885

Superfamily CRANIOIDEA Menke, 1828

Family CRANIIDAE Menke, 1828

Genus *ORTHISOCRANIA* Rowell, 1963

*Orthisocrania divaricata* (M'Coy, 1851)

Figs. 4a, b

1846 *Crania antiquissima* ? Eichwald; M'Coy: 25.

1851 *Pseudocrania divaricata* M'Coy: 187; pi. 1, **H**, figs 1, 2.

1866 *Crania (Pseudocrania) divaricata* M'Coy; Davidson: 78; pi. 8, figs 7- 12.

1994 *Orthisocrania divaricata* (M'Coy, 1851); Parkes Pl. 2, figs 1-8 [and detailed synonymy therein]

2008 *Orthisocrania divaricata* (M'Coy, 1851); Cocks: 38.

*Remarks.* The one specimen known, an internal mould, is from the Geological Survey of Ireland collections (GSI: F11708). Reed (1899) noted Davidson's (1866) record of *Crania divaricata*, but did not identify it himself within the GSI collection. It is insufficient in number and preservation to merit formal description, but appears comparable in all respects to *Orthisocrania divaricata* as described from Longvillian Duncannon Group localities such as Carrigadaggan and Grange Hill, Kildare Inlier by Parkes (1994).

Superfamily STROPHOMENOIDEA King, 1846

Family RAFINESQUINIDAE Schuchert, 1893

Subfamily LEPTAENINAE Hall & Clarke, 1894

Genus *LEPTAENA* Dalman, 1828

*Leptaena* sp.

Fig. 9a

*Remarks.*- A single poorly preserved shell has the characteristic shape of *Leptaena*, but is inadequate for identification to species level. Based solely on its size, *Leptaena minuta* Kiær, 1926 and the variants described by Mitchell (1977) from the Killey Bridge Formation (upper Katian) in the Pomeroy Inlier, Co. Tyrone, is a likely candidate, but cannot be confirmed on this sparse material. The specimen is approximately 9 mm wide and 7 mm long and 5 mm deep, thus comparable in size to Mitchell's species. A similar form is present in the older Bardahessiagh Formation (upper Sandbian-lower Katian) in the same inlier (Candela 2003).

Superfamily PLECTAMBONITOIDEA Jones, 1928

Family SOWERBYELLIDAE Jones, 1928

Subfamily AEGIROMENINAE Havlíček, 1961

Genus *SERICOIDEA* Lindström, 1953

Type species.-*Leptaena sericea* J. de C. Sowerby var. *restricta* Hadding, 1913, p. 62; from the Sularp Shale (Caradoc), Fågelsång, Scania.

*Sericoidea hibernica* sp. nov.

Figs. 6b, c, e-g, i, j

*Name.*- From Hibernia, Latin name for Ireland.

*Holotype.*-Figs. 6e,g, internal mould and cast of a dorsal valve, GSI : F28164, from the silty mudstone of the Raheen Formation (Katian), County Waterford, Ireland.

*Material.*-10 ventral external, nine internal; seven dorsal external and 11 internal moulds from the collection made by Tripp and Morris with the prefix 'b, c and d'.

*Diagnosis.*- Transverse *Sericoidea* species with weakly accentuated ornament, primary ribs unevenly developed, some originating from the umbo, others from the midlength, with 2-5 finer costellae between each. Pair of septules beside the anterior end of the median septum consistently present.

*Description. Exterior.*-Transverse semielliptical shell 1.62-2.7 mm long, 2.43-4.32 mm wide and the length/width ratio 0.57-0.67. Profile evenly and gently concavo-convex. Cardinal extremities acute or nearly rectangular with the maximum width along the hinge line. Ventral interarea apsacline; delthyrium with a very small pseudodeltidium covering posterior one-quarter of delthyrium. Dorsal interarea hypercline, open notothyrium mainly occupied by cardinal process. Ornament of differentiated parvicostellae, the coarser primary ribs unevenly developed, some originating from the umbo, others from the midlength, with 2-5 finer costellae between each. No concentric growth lines are obvious.

*Ventral interior.*-Minute teeth dorsilaterally directed and unsupported. Bilobed muscle field weakly impressed, about one-quarter of shell length and width; a pair of tiny kidney-like adductor scars in the postero-medial part with a very thin and short myophragm; elongate oval diductor scars divergent at about 70°. Elsewhere valve interior covered by densely populated, anteriorly projecting pseudopunctae between weakly impressed ribs.

*Dorsal interior.*-Cardinalia about one-eighth of shell length and one-sixth of shell width; thin, transverse plate-like undercut cardinal process laterally connected with a pair of small socket ridges which are also thin plate-like and divergent at about 120°. Praeculmen septules absent. Poorly impressed muscle field circular in shape, with extremely weak bounding ridges starting from the antero-lateral ends of the socket ridges. Median septum about one-quarter of the shell length, originating from the middle of the muscle field, extending higher and higher, and reaching its peak at the anterior end. A series of anteriorly projecting and irregularly but symmetrically distributed tubercles just in front of the muscle field. Elsewhere valve interior finely pustulate and external ornament impressed.

*Remarks.*-The differentiated ornamentation and relatively fewer dorsal tubercles on our material suggest assignment to *Sericoidea*, distinguishing the species from those of the contemporary plectambonitoid *Chonetoidea*. Key, however, is the lack of praeculmen septules (Candela 2011) which more definitively places the species in the former genus. The number of the tubercles is



variable, one of the smallest specimens has only three pairs while most of the adults have five pairs of much stronger tubercles; but the pair beside the anterior end of the median septum is always present and the strongest, irrespective of the shell sizes. The ornament impressed on the inner shell surface also varies consistently with the shell size, covering the whole internal surface in small individuals but present only along the marginal area in adults.

*S. hibernica* belongs to a species group having a small number of dorsal septules, irregularly developed and with variably present median septa. It thus has some similarities to *S. restricta* Hadding, 1913 from the Sandbian and lower Katian of Scania, southern Sweden, *S. minor* Percival, 1979 and *S. sejuncta* Percival, 1979. It differs from the first in having a less well-developed median septum and a more weakly accentuated ornament. The latter two, Caradoc Australian species, are similar to each other and differ from the Irish material in having finer, more clearly differentiated ornaments. *Sericoidea gamma* (Spjeldnæs 1957), erected on the basis of material from the Nakkholmen Formation (upper Caradoc) in the Asker district was also documented in the same formation on the island of Nakkholmen, Bunnefjord, Oslo (see also Harper *et al.* 1985, p. 305, fig. 6B, E-J); it is very similar to our Raheen material. It has been synonymised with *S. craigensis* (Reed, 1917) from Kiln Mudstones (Katian) in the Craighead Inlier, Girvan (Candela 2011). On Nakkholmen it occurs together with *Onniella* and a few others constituting a low-diversity, deep-water brachiopod fauna. The only difference is that the Nakkholmen specimens have a relatively shorter dorsal median septum and smaller cardinalia.

*Sericoidea homolensis* Havlíček (Hurst 1979, p. 280, figs 445-456), from the Onny Shale Formation (upper Caradoc) on the River Onny, southern Shropshire, is similar to *S. hibernica* but differs in having a poorly-differentiated ornamentation, more and stronger dorsal tubercles, and larger and more divergent lobes on ventral muscle field. This species, however, has praeculmen septules and has recently been reassigned to *Chonetoidea* (Candela 2011).

Family SOWERBYELLIDAE Öpik, 1930

Subfamily SOWERBYELLINAE Jones, 1928

Genus *SOWERBYELLA* Jones, 1928

*Sowerbyella* sp.

Figs 6a, d, h

*Remarks.* The GSI collections include interiors of one ventral and one dorsal valve that are indicative of the genus; the ventral interior displays the insertion of setae around the shell margins and dorsal valve, is much smaller, but nevertheless possesses a bema with a pair of central side septa. There is a series of projected tubercles along the margin of the visceral area; the strongest of tubercles, positioned centrally, representing a median septum. Otherwise the genus is probably only represented by shell fragments of external ribbing in the other collections.

Genus *LEANGELLA* Öpik, 1933

Subgenus *LEANGELLA (LEPTESTIINA)* Havlíček, 1952

*Leangella (Leptestiina)* sp.

Figs. 5d, g-i

1899 *Plectambonites quinquecostata* M'Coy; Reed, p. 723.

*Remarks.* Sufficient dorsal and ventral internal moulds and some exteriors are present to be confident that this genus is present although the preservation is inadequate to warrant a specific identification. The size and proportions of this material compare well with *Leangella (Leptestiina) oepiki* recorded from the Duncannon Group localities of early Caradoc (Burrellian) age in south east Ireland (Parkes 1994).

Family LEPTELLINIDAE Ulrich & Cooper, 1936

Subfamily PALAEOSTROPHOMENINAE Cocks & Rong, 1989

Genus *PALAEOSTROPHOMENA* Hortedahl, 1916

*Palaeostrophomena* sp.

Figs. 5a-c, e, f

*Remarks.* A number of ventral valves are present within the total assemblage, but their overall appearance with strophic hinge, lateral rugae and ventral muscle scar are typical of *Palaeostrophomena*, a genus which is widely distributed in rocks of Sandbian and Katian age.

Class RHYNCHONELLATA Williams *et al.*, 1996

Order PROTORTHIDA Schuchert & Cooper, 1931

Superfamily SKENIDIOIDEA Kozłowski, 1929

Family SKENIDIIDAE Kozłowski, 1929

Genus SKENIDIOIDES Schuchert & Cooper, 1931

*Skenidioides* sp.

Figs. 7a-e

*Remarks.* Only a small number of broken and indistinctive valves of this genus are noted, but they are sufficient to be certain that this genus is present in the Raheen Formation.

Order ORTHIDA Schuchert & Cooper, 1932

Suborder ORTHIDINA Schuchert & Cooper, 1932

Superfamily ORTHOIDEA Woodward, 1852

Family ORTHIDAE Woodward, 1852

Genus SULEVORTHIS Jaanusson & Martna, 1948

*Sulevorthis* sp.

Fig. 7f, g, j, k

1899 *Orthis calligramma* Dalm.; Reed, p. 723.

*Remarks.* Only four specimens from different levels are recorded of this small, coarse ribbed, orthid together with a few specimens in the collections of the Geological Survey of Ireland.

Family HESPERORTHIDAE Schuchert & Cooper, 1931

Genus *PTYCHOPLEURELLA* Schuchert & Cooper, 1931

*Ptychopleurella* sp.

Figs. 7n, o

*Remarks.* A single broken dorsal valve interior of this genus is present but is insufficient to identify the species. A very small exterior of a ventral valve, with strong concentric growth lamellae, is strongly reminiscent of *Ptychopleurella lapworthi* Harper, 1986 from the Girvan succession, but is also similar to the *Glyptorthis* sp. figured by Harper and Mitchell (1982, fig 2B, 2C) from the Katian Oriel Brook Mudstone of eastern Ireland.

Family PRODUCTORTHIDAE Schuchert & Cooper, 1931

Subfamily PRODUCTORTHINAE Schuchert & Cooper, 1931

Genus *NICOLELLA* Reed, 1917

*Nicolella* sp.

Figs. 7h, i, l, m

*Remarks.* Several ventral valves are assigned to *Nicolella* on the basis of their coarse, sharp-crested costae and ventral muscle scars.

Superfamily DALMANELLOIDEA Schuchert, 1913

Family DALMANELLIDAE Schuchert, 1913

Subfamily DALMANELLINAE Schuchert, 1913

Genus *ONNIELLA* Bancroft, 1928

*Type species.* *Onniella broeggeri* Bancroft 1928, p. 46; from the Onny Shale Formation (Onnian), south Shropshire, England.

*Onniella variabilis* sp. nov.

Figs 8a-p

1846 *Orthis elegantula* Dalman; M'Coy: 29.

1865 *Orthis elegantula* Dalman; Du Noyer and Baily: 18-26.

1899 *Orthis argentea* His.; Reed, p. 723.

*Name.*- Alluding to the large amount of morphological variation recorded for the species.

*Holotype.*-Figs. 8g, h, internal mould of a dorsal valve, GSI : F12420, from the silty mudstone of the Raheen Formation (Katian), County Waterford, Ireland.

*Material.*-70 ventral external, 73 internal; 82 dorsal external and 77 internal moulds from the collections made by Tripp and Morris, and Harper and Mitchell with the prefix 'a, b, c and d', but mainly of prefix 'd'. 12 ventral external; 31 internal; 20 dorsal external and 27 internal moulds from the GSI collections.

*Diagnosis.*- Small, transverse to subcircular *Onniella* species with persistent but shallow dorsal sulcus; costellae, generally fascicostellate, branching three times or more, about 5-7 per mm at the 3 mm growth stage; cardinal process varies from simple ridge to differentiated bilobed myophore.

*Description.*- Exterior.-Small, transverse subcircular shell 1.71-7.92 mm long, 2.16-8.46 mm wide and the length/width ratio 0.73-0.97, mean 0.80. Profile, ventri-biconvex with the greatest curvature in postero-medial part of shell. Shallow, dorsal sulcus starting from the umbo, about one-quarter to one-third of the shell width near the anterior margin; ventral valve evenly convex. Cardinal extremities rounded, maximum width near the shell midlength. Ventral interarea high, flat and apsacline; delthyrium mainly open, with a very small endodelthyrial plate covering its top part and posterior end. Dorsal interarea short, flat and anacline with open notothyrium. Ornament of costellae, generally fascicostellate, branching for three times or more, about 5-7 per mm at the 3 mm growth stage, normally with median interspace on dorsal valve and median rib on ventral valve. Evenly populated concentric fila covering the entire shell surface, about 21 per mm; a few well-developed concentric lamellae irregularly distributed on the shell antero-medial part, cutting through all the radial lines.

*Ventral interior.*-Triangular teeth strong, dorsally directed; dental plates short, thick and variably divergent. Well-impressed muscle field occupying the entire deep delthyrial cavity, open antero-laterally, and about one-quarter of shell length and one-sixth of shell width; adductor scars slightly elevated while the diductor scars on both sides a little more elongate. Lemniscate pallial markings rarely preserved, vascular media originating from two anterior ends of diductor scars. Ornament impressions along the marginal area or covering the whole internal surface except for the muscle field.

*Dorsal interior.*-Well-developed cardinalia about one-fifth to one-seventh of the shell length and width; cardinal process with a variably developed base and a well-differentiated myophore which is always at the posterior end of the notothyrial cavity; small and deep sockets with variably developed antero-lateral pads; triangular strong brachioophores antero-ventrally directed, with or without brachioophore plates which are usually short, subparallel and merged to both sides of the myophragm. High and thick myophragm posteriorly connected with the cardinal process base and anteriorly continuous with the wider but lower median ridge. Small quadrate muscle field just in front of the cardinalia, about one-third to one-quarter of the shell length and width, two pairs of kidney-like adductor scars on both sides of the myophragm and two pairs (anterior and posterior) about the same size. Vascular media originating from the anterior ends of the muscle field, and vascula myaria coming out from the junction of the anterior and posterior pairs of adductor scars. Ornamental impressions often on the anterior one-third of the internal surface of shell.

*Remarks.*-From the available specimens, several key areas of population variation are clearly apparent: (1) concentric lamellae; usually only 3-4 apparent concentric lamellae appearing on the shell anterior half, but some specimens have no lamellae and some others have nearly 10 lamellae amongst which one or two are developed on the posterior part of the shell; (2) ornament impression; for smaller shells, this impression usually covers a large area or even the entire internal surface except for the muscle field, while for those adults, this impression only appears in the anterior one-third or less of the shell; (3) dental plates; usually thick, short and slightly divergent, but some specimens,

especially the juveniles, have much thinner, relatively longer and more divergent dental plates functioning as the lateral bounding ridges of the muscle field; (4) cardinal process; some have a very thick and low base, situated on the notothyrial platform, but others only have a well-differentiated cardinal process at the posterior end; (5) brachiophore plates; those with a weaker cardinal process usually have a pair of thin, short and subparallel brachiophore plates while the others have no such plates, instead, a well-developed notothyrial platform is present; (6) socket pads; most dorsal valves lack this kind of structure, but a few dorsal valves have a pair of well-developed thick socket pads bounding the sockets antero-laterally.

Similar variation within *Onniella* species was recorded by Hurst (1979) from the upper Caradoc of south Shropshire, where the author recognized that several established species (such as *O. reuschi*, *O. grandis* and *O. aspasia*) are conspecific with *O. reuschi* Bancroft, 1928 having priority. The great variation of the cardinal process also occurs within the population of one species of *Ptychopleurella*, *P. bouchardi* (Davidson) from the Wenlock Limestone at Wenlock Edge, Shropshire, where the cardinal process varied from none (smallest specimens) through thin plate-like (juveniles) to thick and high ridge (adults) (Bassett 1970, p. 299, pl. 53, figs 1-15). The new Raheen species is small with a shallow sulcus and broad fold. The ribbing pattern is fascicostellate and more rarely parvicostellate, with dorsal costellae arising by internal branching to form bundles. Significantly the shells are characterised by a dorsal median interspace, a feature characterising cool-water higher latitude dalmanelloid taxa (Jin and Harper 2015). The *Onniella bancrofti* species group including the type species and *O. cf. bancrofti* Lindström (Harper *et al.* 1985), from the deep-water Nakkholmen Formation (upper Caradoc) on the island Nakkholmen in the Bunnefjord, is very close to our new species except for its generally larger shell, slightly coarser costellae, persistent ventral fold and marked dorsal notothyrial platform, and stronger and longer, curving dental plates.

Superfamily ATRYPOIDEA Gill, 1871

Family LISSATRYPIDAE Twenhofel, 1914

Subfamily SEPTATRYPINAE Kozłowski, 1929

Genus *IDIOSPIRA* Cooper, 1956

Type species.-*Camerella panderi* Billings 1859, p. 302 (*illustr.* Billings, 1863, p. 143, fig. 78a-b), Rockland Formation, Paquette Rapids, Alumette Island, Ontario; Sandbian.

*Idiospira?* sp.

Figs 9b, c

*Remarks.* Only three incomplete ventral internal moulds are available, but their small, convex smooth shells, nonstrophic hinge line and a pair of slightly divergent (at about 30°) well-developed dental plates suggest assignment to the widespread Late Ordovician smooth atrypoid *Idiospira*. According to Copper's (1986) revision, *Idiospira* is of early Katian age and is reported from several localities in Ireland and Britain, such as *I. plicata* (Mitchell 1977, p. 127, pl. 17, figs 29-32) from the Bardahessiagh Formation at Pomeroy, County Tyrone, Ireland; *I. sulcata* (Williams 1962, p. 254, pl. 25, figs 47, 53, 58-60) from the Kiln Mudstone at Craighead, Girvan; and *I. thomsoni* (Davidson 1869, p. 186, pl. 24, fig. 18) from the Craighead Limestone at Craighead Quarry, Girvan, Scotland. They differ from our material in having a pair of curved dental plates (*I. plicata*), a strong ventral sulcus (*I. sulcata*) and large size with marked trigonal outline (*I. thomsoni*).

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## Figure captions

Figure 1. Location map of the Raheen locality, Newtown Head, Co. Waterford, Ireland.

Figure 2. The Raheen fauna is compared with other closely coeval assemblages from elsewhere using non-metric multidimensional scaling (NMDS), analysed by the Raup-Crick coefficient. The database is that assembled in Harper *et al.* (2013) for the lower Katian, see <http://www.geolsoc.org.uk/SUP18667>.

Figure 3. Obolid: a, partially exfoliated ventral exterior, GSI : F12435. *Paracraniops* sp.: b, ventral interior, GSI : F12437; c, ventral valve, GSI : F12427; d, ventral valve, GSI : F12428; e, ventral valve, GSI : F12436. Scale bars 5 mm. Paterulid: f, dorsal valve, GSI : F12433. Scale bar 2.5 mm; g, ventral valve, GSI : F12434. Scale bar 1.25 mm.

Figure 4. *Orthisocrania divaricata* (M'Coy, 1851): a, b, internal mould and cast of ventral valve, GSI : F11708.

Figure 5. *Palaeostrophomena* sp.: a, external mould of ventral valve, GSI : F12426; b, e, external mould and cast of dorsal valve, GSI : F12424; c, f, internal mould and cast of ventral valve, GSI : F7553. *Leangella (Leptestiina)* sp.: d, g, internal mould and cast of ventral valve, NMING : F30756A; h, i, internal mould and cast of incomplete dorsal valve, NMING : F30758. Scale bars 5mm.

Figure 6. *Sowerbyella* sp.: a, h, internal mould and cast of ventral valve, GSI : F11703; d, internal mould of dorsal valve, NMING : F30742B. Scale bars 5 mm. *Sericoidea hibernica* sp. nov.: b, external mould of dorsal valve, NMING : F30742A; c, internal mould of dorsal valve, NMING : F30741; e, g, holotype, internal mould and cast of dorsal valve, NMING : F28164; f, i, internal and

external mould of ventral valve, NMING : F30758; j, internal mould of dorsal valve, NMING : F28109. Scale bars 1.25mm.

Figure 7. *Skenidioides* sp.: a, external mould of dorsal valve, NMING : F30740B; b, internal mould of dorsal valve, NMING : F30740A; c, d, internal and external moulds of dorsal valve, NMING : F30736; e, internal mould of dorsal valve, NMING : F30747; *Sulevorthis* sp.: f, g, external mould and cast of dorsal valve, GSI : F12431. Scale bars 5 mm; j, external mould of dorsal valve, GSI : F11699 ; k, internal mould of dorsal valve, GSI : F11560, counterpart of GSI : F11699. Scale bars 2.5mm; *Nicolella* sp.: h, external mould of ventral valve, NMING : F30744B; i, internal mould of ventral valve, NMING : F30744A; l, m, internal mould and cast of ventral valve, NMING : F30737A. Scale bars 5 mm. *Ptychopleurella* sp.: n, o, external mould and cast of ventral valve, NMING : F30754. Scale bars 2.5mm.

Figure 8. *Onniella variabilis* sp. nov.: a, b, internal mould and cast of dorsal valve, NMING : F30753B, c, external mould of dorsal valve, NMING : F30753A; d, e, internal mould and cast of dorsal valve, NMING : F30739; f, j, external mould and cast of dorsal valve, NMING : F30738; g, h, holotype, internal mould and cast of dorsal valve, GSI : F12420; i, cast of dorsal exterior, NMING : F30735; k, l, internal mould and cast of ventral valve, GSI : F12414; m, p, external and internal moulds of ventral valve, NMING : F30743A; n, o, internal mould and cast of ventral valve, NMING : F30743B. Scale bars 5mm.

Figure 9. *Leptaena* sp., a, internal mould of ventral valve, NMING : F30749A; *Idiospira?* sp.: b, internal mould of ventral valve, NMING : F28245; c, internal mould of ventral valve, NMING : F30746. Scale bars 5mm.

Table 1. List of brachiopod species, valve and preservation types and their distribution in samples of the Raheen Formation. C= conjoined valves, pvi = ventral valve interior, pve = ventral valve exterior, bvi = dorsal valve interior, be = dorsal valve exterior.

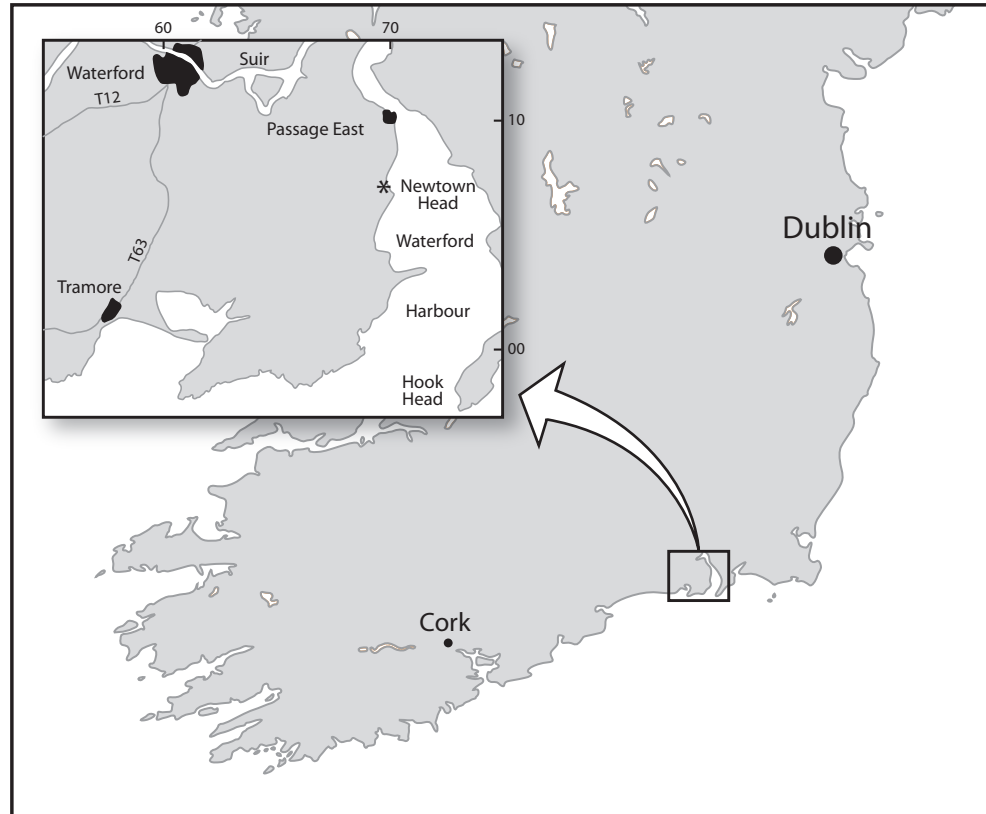
David A. T. Harper  
Department of Earth Sciences  
Durham University  
Durham DH1 3LE  
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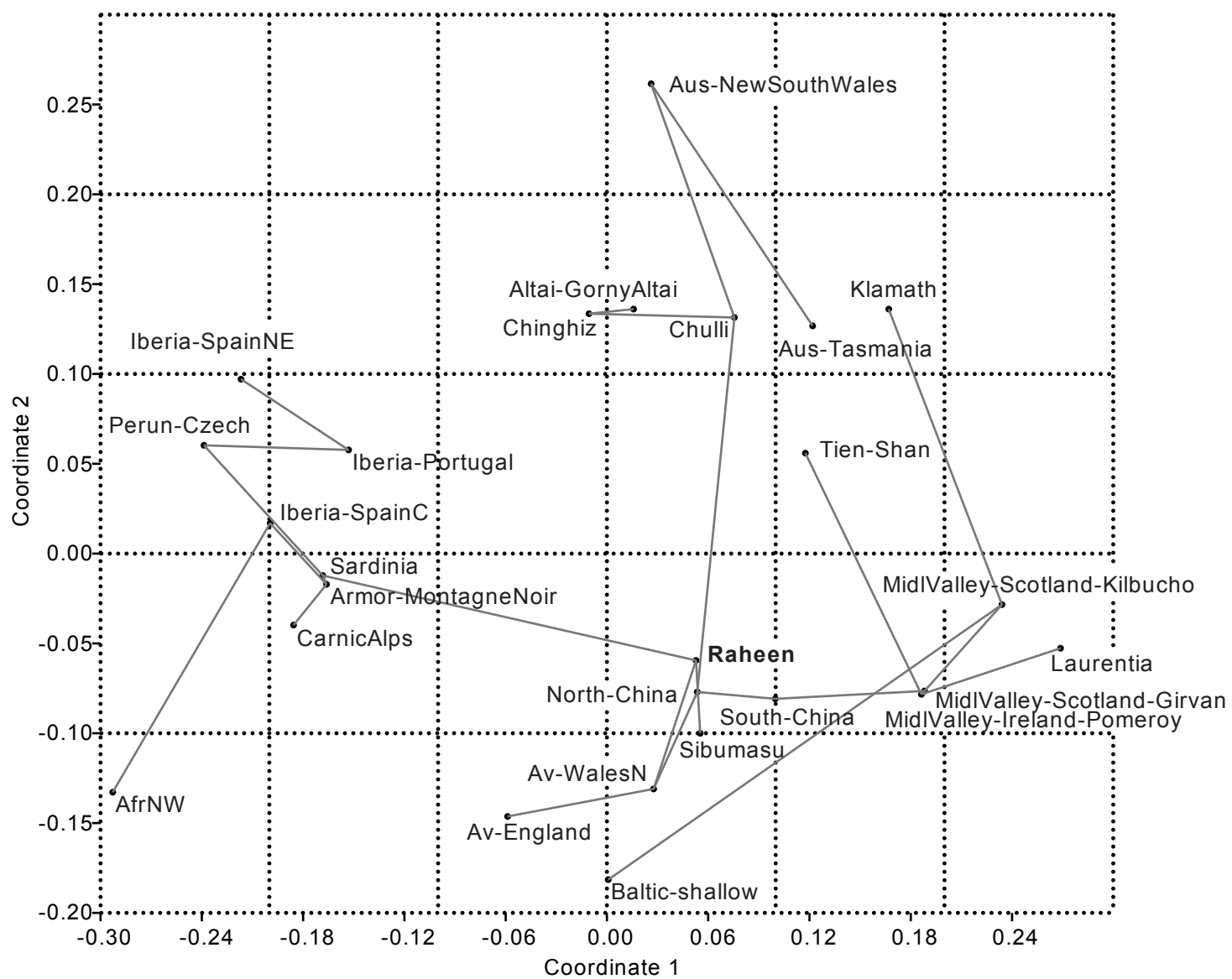
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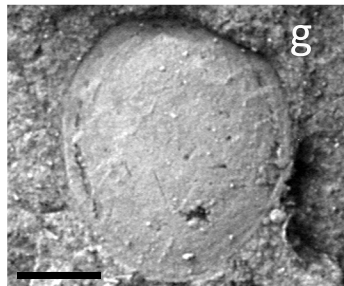
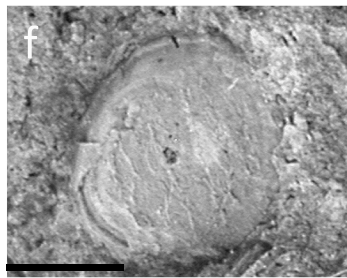
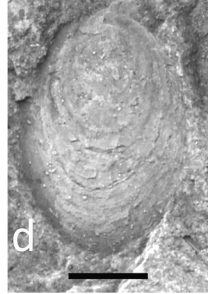
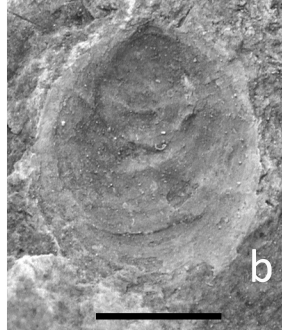
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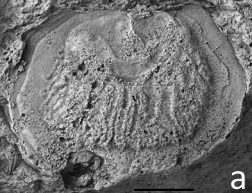
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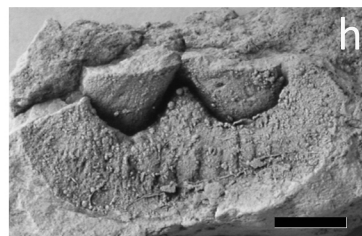
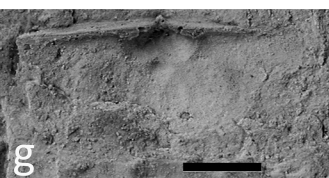
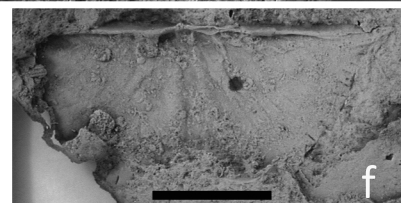
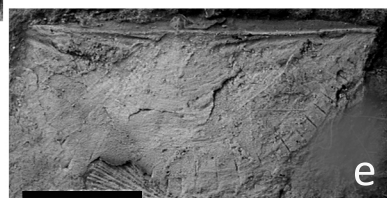
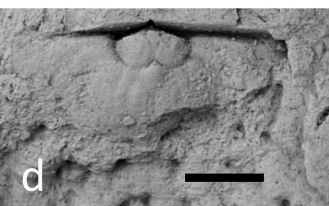
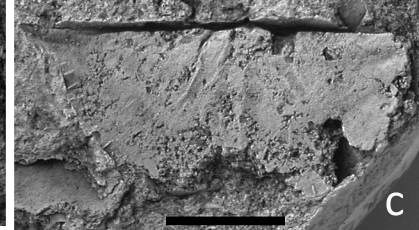
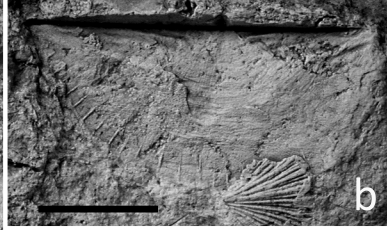
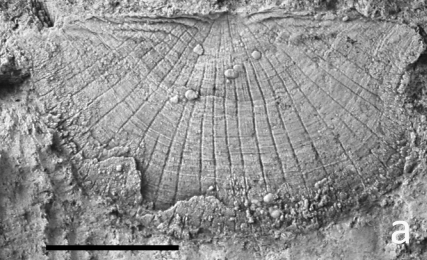


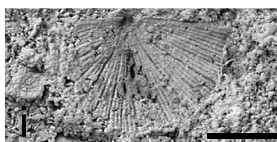
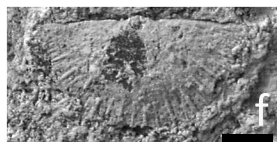
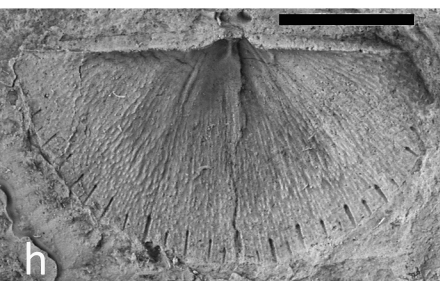
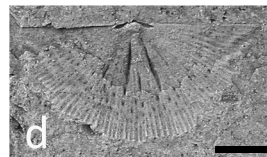
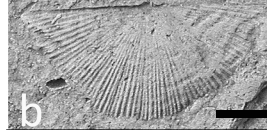
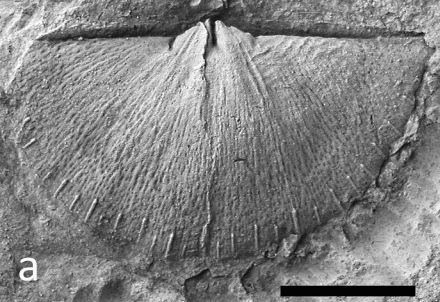


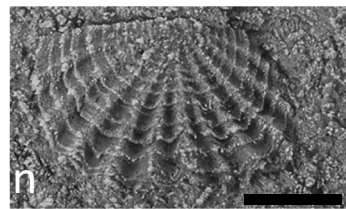
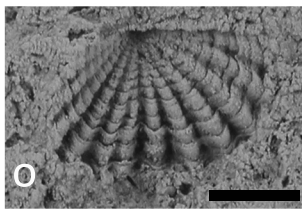
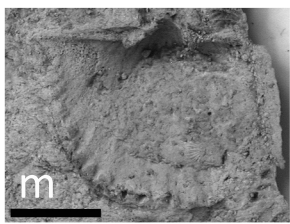
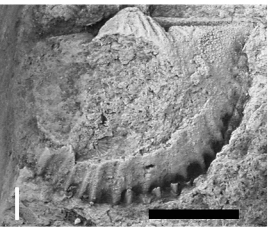
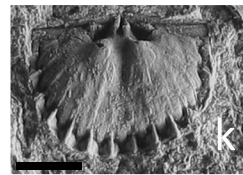
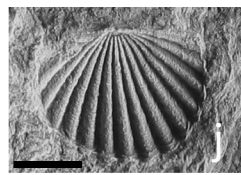
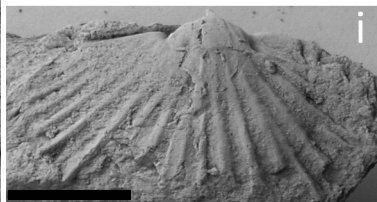
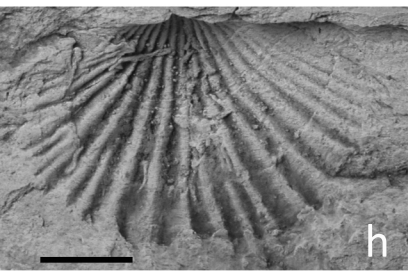
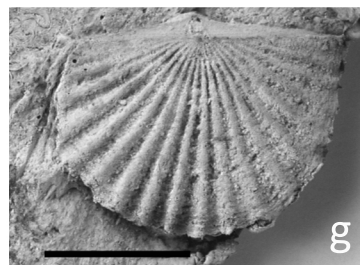
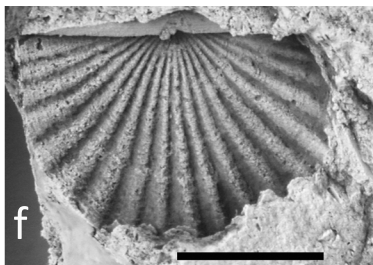
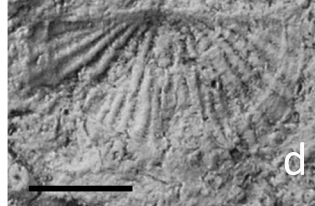
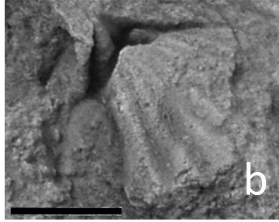
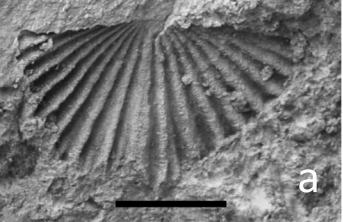


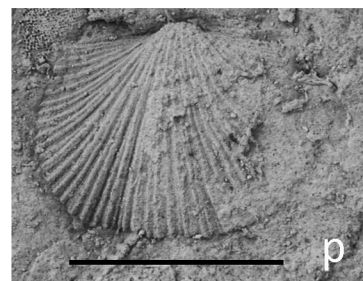
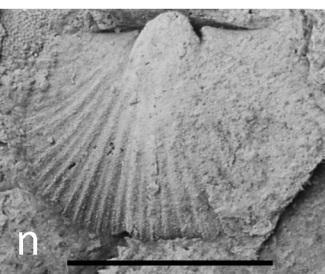
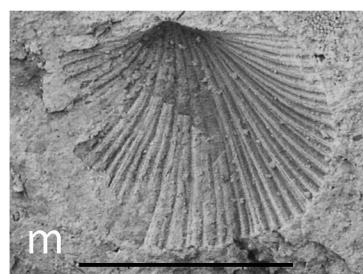
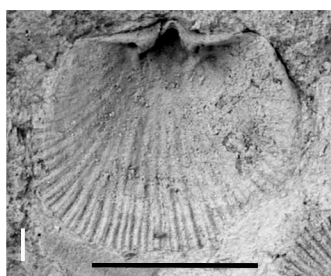
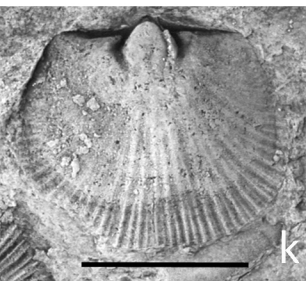
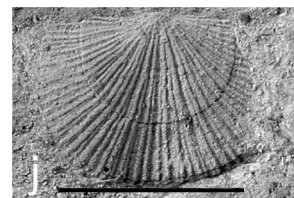
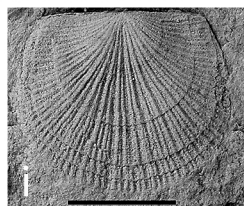
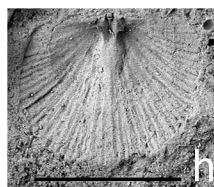
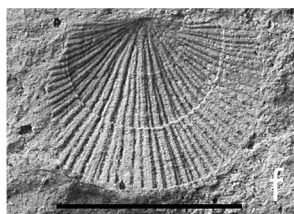
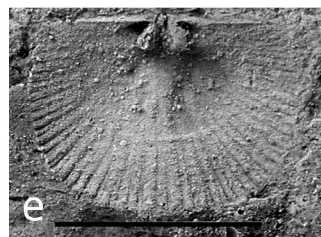
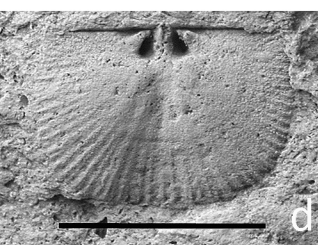
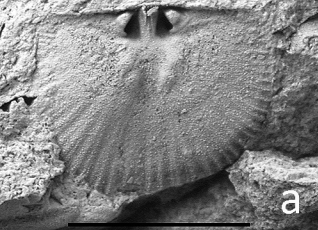


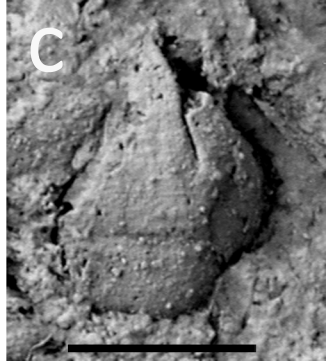
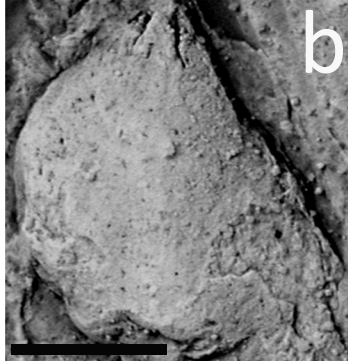
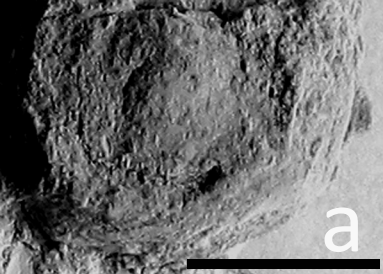












Horizon	Onniella					Sericoidea					Leptestiina					Sowerbyella					Nicolella					Sulevorthis					Skenidioides					paterulid	linguloid'	Palaeos trophom ena	Idi os pir a	Orthiso crania	Ptychople urella
	c	pvi	pve	bvi	bve	c	pvi	pve	bvi	bve	c	pvi	pve	bvi	bve	c	pvi	pve	bvi	bve	c	pvi	pve	bvi	bve	c	pvi	pve	bvi	bve											
N of stream	10	56	46	43	48	0	7	5	15	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		3	0	1	0	0				
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Level 8	3	21	25	18	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0					
18" below previous base	1	6	3	0	1	0	2	1	2	3	0	2	1	3	2	0	0	0	2	2	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1				
5' below top	1	6	6	4	7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0					
Raheen shales' - unlocalised	1	11	14	9	10	0	1	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0					
GSI Colln - Raheen shales	0	36	14	34	20	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	2	0	0	0	0	0	3	10	7	0			
Total number in collection	31	200	170	165	194	1	21	17	25	40	0	4	2	4	2	0	1	0	2	3	0	3	3	0	0	0	2	2	1	2	0	1	0	2	3	9	18	10	2	1	3